Engineering Thermodynamics (ME 210)

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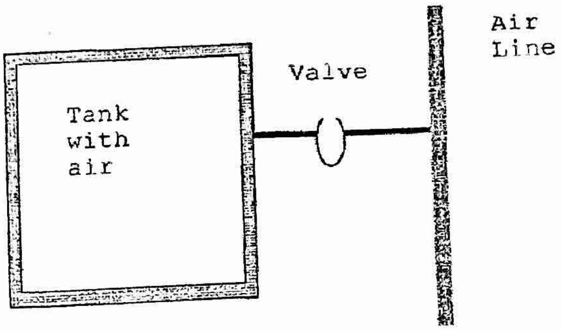
Selected Problems

A 0.2 m^3 rigid tank with air at 1 MPa, 400 K is connected to an air line. The valve is opened and the air flows into the tank until the pressure reaches 10 MPa, at which point the valve is closed and the temperature inside is 700K.



3 (a) State any assumptions used to solve this problem.

- AIR BEHAVES LIKE IDEAL GAS
- THE TANK IS RIGID
- MASS IS CONSTANT (NO LEAKS) ↳ after it is added

$R = 0.287 \, kJ/kgK$

(b) What is the mass of the air in the tank before and after the process?

State ① $P_1 = 1MPa \quad T_1 = 400K$ solve for $v_1 = \frac{RT_1}{P_1} = \frac{0.287(400)}{1000} = 0.1148 \, m^3/kg$

$$m_1 = \frac{V_1}{v_1} = \frac{0.2}{0.1148} = \underline{\underline{1.74kg}}$$

State ② $P_2 = 10MPa, \; T_2 = 700K \quad v_2 = \frac{RT_2}{P_2} = \frac{0.287(700)}{10{,}000} = 0.02 \, m^3/kg$

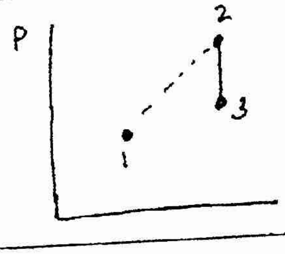
$$m_2 = \frac{V_2}{v_2} = \frac{0.2}{.02} = \underline{\underline{10.0 \, kg}}$$

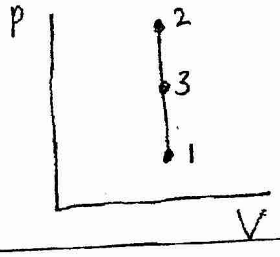
(c) The tank eventually cools to room temperature, 300 K. What is the pressure inside the tank then?

State ③ $v_3 = v_2 = 0.02 \quad T_3 = 300K$

$$P_3 = \frac{RT_3}{v_3} = \frac{(0.287)(300)}{0.02} = \underline{\underline{4.3MPa}}$$

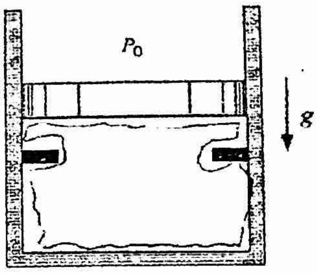
(d) Show this process on a P-v diagram





Consider the piston/cylinder arrangement shown to the right. 5 kg of water at 400 °C, 300 kPa are contained in the cylinder (state 1). The water is cooled until the volume is 1.0 m^3 at which point the piston just rests on the stops (state 2). The water is then further cooled until the pressure in the cylinder is 100 kPa (state 3). At this point the ~~weights are removed and the~~ stops are removed and the system is cooled to a saturated liquid state (state 4).

(weights are removed
such that P_{lift} = 100 kPa



P (kPa)	T (°C)	v_f (m^3/kg)	v_{fg} (m^3/kg)	v_g (m^3/kg)
100	99.62	0.001043	1.69296	1.694
300	133.55	0.001073	0.60475	0.60582

(a) List any assumptions used in the solution of this problem.

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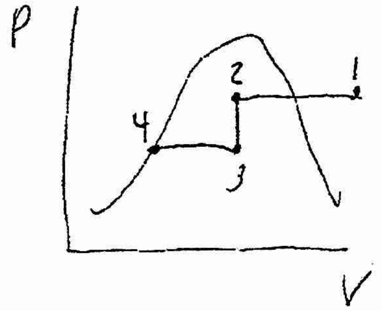
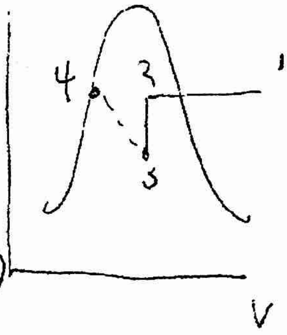
QE process
no friction
no leaks (constant mass)

(b) Draw the process on a Pv diagram.

4



or
(depending
on your
interpretation)



(c) Calculate the volume at state 1 and the pressure and temperature at state 2.

10

State ① : $m = 5\,kg$
$T = 400°C$
$P_1 = 300\,kPa$ } superheated
$v_1 = 1.03151\ m^3/kg$
$V_1 = v_1 m = \underline{5.158\ m^3}$

state ② $P_2 = P_1 = \underline{300\,kPa}$ $v_2 = V_2/m = 1/5 = 0.2\ \frac{m^3}{kg}$
mixture
$\underline{T = 133.6°C}$

(d) Calculate the final pressure, temperature and volume of the system.

at state ③ : $P_3 = 100\,kPa$
$v_3 = v_2$

State (4a) $P_4 = P_3 = \underline{100\,kPa}$
$v_4 = v_f = \underline{0.001043}$
$T = T_{sat} = \underline{99.6°C}$
$V_4 = 5(v_4) = .0052$

State (4b) $P_4 = \underline{300\,kPa}$
$v_4 = v_f = \underline{.001073}$
$T_4 = \underline{133.5°C}$
$V_4 = 5v_4$
$= .0054$

(e) Calculate the amount of work done during this process.

$W = \int P dV$

(a)

$W = P_1(V_1 - V_2) + P_3(V_2 - V_4)$

$= 300(5.158 - 1) + 100(1 - .0052)$

$= \underline{1.35 kJ}$

or is process is assumed linear:

$W = P_1(V_1 - V_2)$

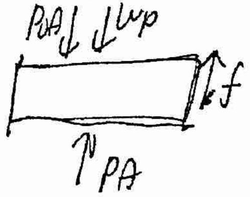
$+ (P_3 + P_4)/2 (V_2 - V_4)$

$= 300(5.138 - 1)$

$+ 250(1 - .0054)$

$= 1.8 kJ$

(f) Without performing any further calculations, explain how your answers to parts (d) and (e) would change if there was significant friction in the system.

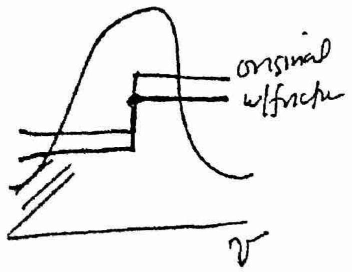


$PA = P_0A + W_p \mp f$

Friction works to oppose motion

~~[illegible] decrease/decrease~~

~~work would increase~~



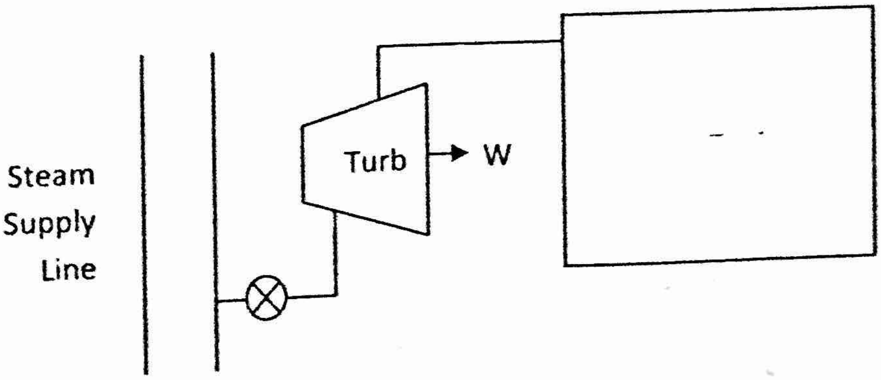
as system cools, P_{sat} would decrease due to the effects of friction since P decrease, T decreases as does v_f.

work would decrease

Problem 13. A steam supply line provides steam at a temperature of 600 °F and a pressure of 500 lbf/in^2. The valve is opened, and steam flows through a turbine and into an evacuated tank (volume = 10 ft^3). When the pressure in the tank equals the supply line pressure the valve is closed. The work output of the turbine during this process is 85 Btu/lbm of steam. Assuming the process to be adiabatic, find:

(a) The temperature of the steam in the tank.

(b) The amount of steam that enters the tank.



1) *Consider the steam power plant modified with regeneration and reheat as shown in Figure (4), which also supplies steam to a process heater.*

Steam enters the high pressure turbine at 6 MPa and 450°C, and expands to a pressure of 0.4 MPa. At this pressure, 60% of the steam is extracted, and the rest is routed to the reheater to be heated to 400°C.

Part of the extracted steam is used to heat feed water in an open feed water heater. The rest of the extracted steam is used in the process heated. This steam leaves the process heater as saturated liquid is pumped to boiler pressure.

The reheated steam at 400°C is expanded in the low pressure turbine to 10 kPa.

The following data are available;

$h_1 = 191.83$ kJ/kg
$v_1 = 0.00101$ m^3/kg

$v_4 = 0.001084$ m^3/kg
$h_3 = h_4 = h_{10} = 604.74$ kJ/kg

$h_8 = 3273.4$ kJ/kg
$s_8 = 7.8985$ kJ/kg.K

$h_6 = 3301.8$ kJ/kg
$s_6 = 6.7193$ kJ/kg. K

a) Determine the mass flow rate of steam through the boiler for a net power output of 1 MW
b) Determine the heating load on the process heater
c) Determine the thermal efficiency of the plant.

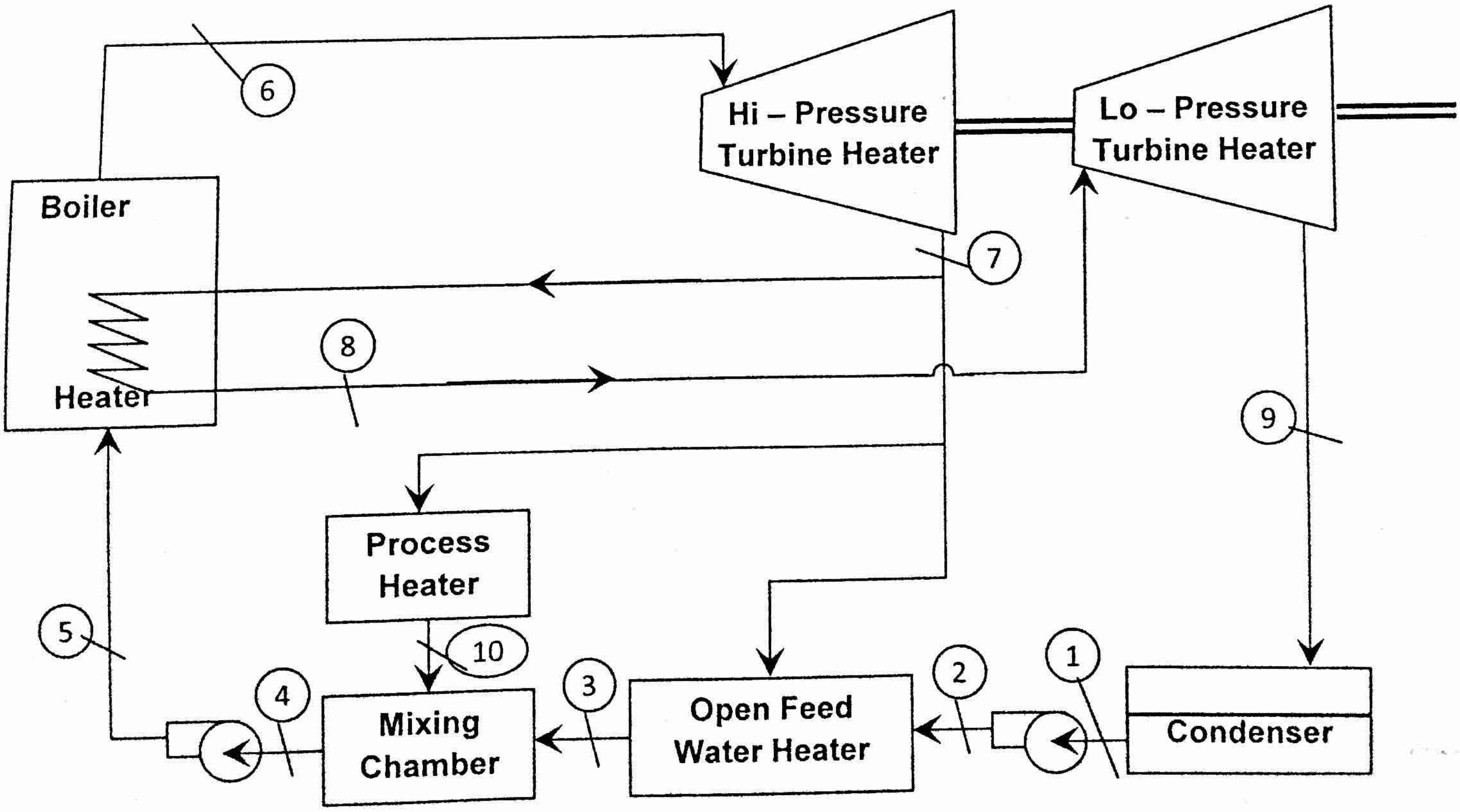
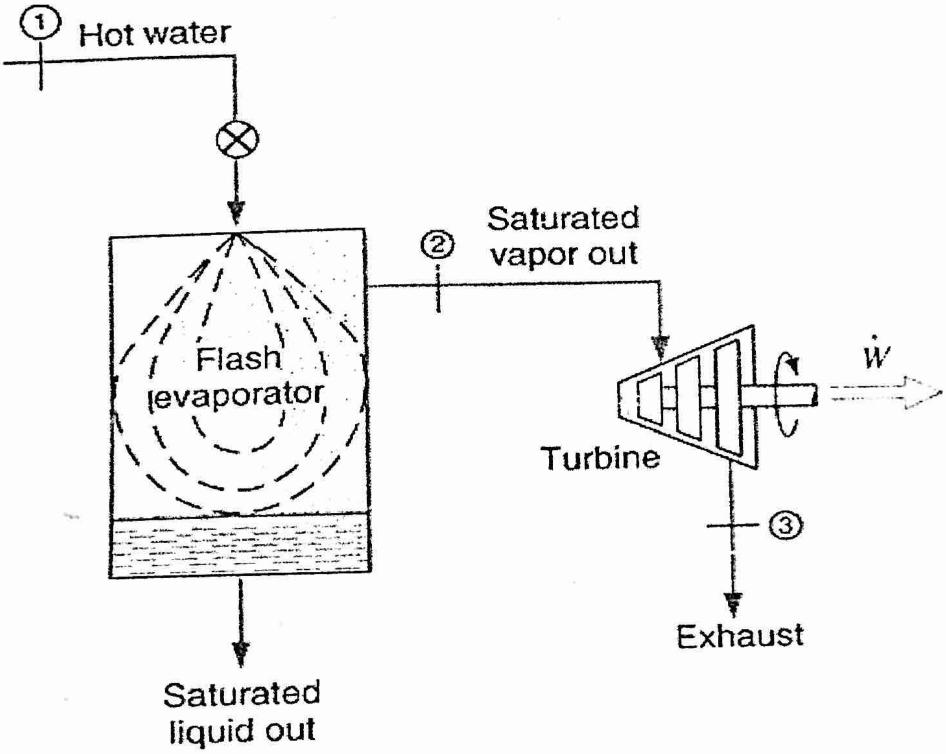


Figure (4)

1) A proposal is made to use a geothermal supply of hot water to operate a steam turbine, as shown in the figure below. The high-pressure water at 1.5 MPa, 180 °C, is throttled into a flash evaporator chamber, which forms liquid and vapor at a lower pressure of 400 kPa. The liquid is discarded while the saturated vapor feeds the turbine and exits at 10 kPa, 90% quality. If the turbine should produce 1 MW, find the required mass flow rate of hot geothermal water in kilograms per hour.

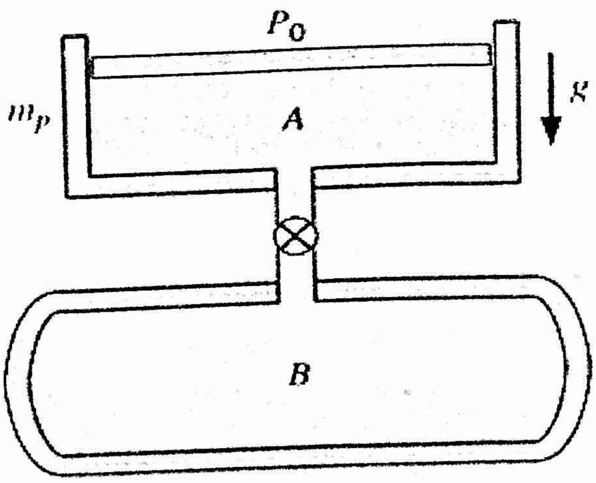


2) The cylinder volume below the constant loaded piston has two compartments A and B filled with water. A has 0.5 kg at 200 kPa, 150 ºC and B has 400 kPa with a quality of 50% and a volume of 0.1 m^3. The valve is opened and heat is transferred so the water comes to a uniform state with a total volume of 1.006 m^3.

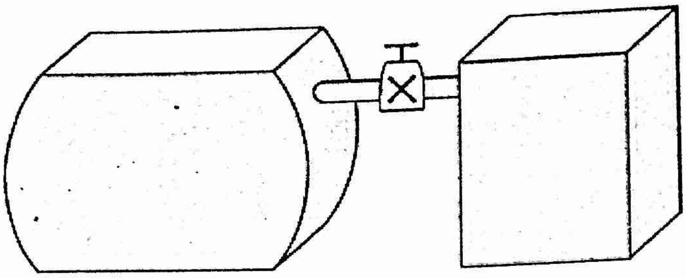
i) Find the total mass of water and the total initial volume.

ii) Find the work in the process

iii) Find the process heat transfer.



3) A 1 m^3 tank containing air at 25 °C and 500 kPa is connected through a valve to another tank containing 4 kg of air at 60 °C and 200 kPa. Now the valve is opened and the entire system reaches thermal equilibrium with the surroundings at 20 °C. Assume constant specific heat at 25 °C and determine the final pressure and the heat transfer.



6.106 A somewhat simplified flow diagram for a nuclear power plant is given in Fig. P6.106. Mass flow rates and the various states in the cycle are shown in the accompanying table.

The cycle includes a number of heaters in which heat is transferred from steam, taken out of the turbine at some intermediate pressure, to liquid water pumped from the condenser on its way to the steam drum. The heat exchanger in the reactor supplies 157 MW, and it may be assumed that there is no heat transfer in the turbines.

(a). Assuming the moisture separator has no heat transfer between the two turbine sections, determine the enthalpy and quality ($h4$, $x4$).

(b). Determine the power output of the low-pressure turbine.

(c). Determine the power output of the high-pressure turbine.

(d). Find the ratio of the total power output of the two turbines to the total power delivered by the reactor.

Point	$\dot{m}$, kg/s	P, kPa	T, °C	h, kJ/kg
1	75.6	7240	sat vap	
2	75.6	6900		2765
3	62.874	345		2517
4		310		
5		7		2279
6	75.6	7	33	138
7		415		140
8	2.772	35		2459
9	4.662	310		558
10		35	34	142
11	75.6	380	68	285
12	8.064	345		2517
13	75.6	330		
14				349
15	4.662	965	139	584
16	75.6	7930		565
17	4.662	965		2593
18	75.6	7580		688
19	1386	7240	277	1220
20	1386	7410		1221
21	1386	7310		

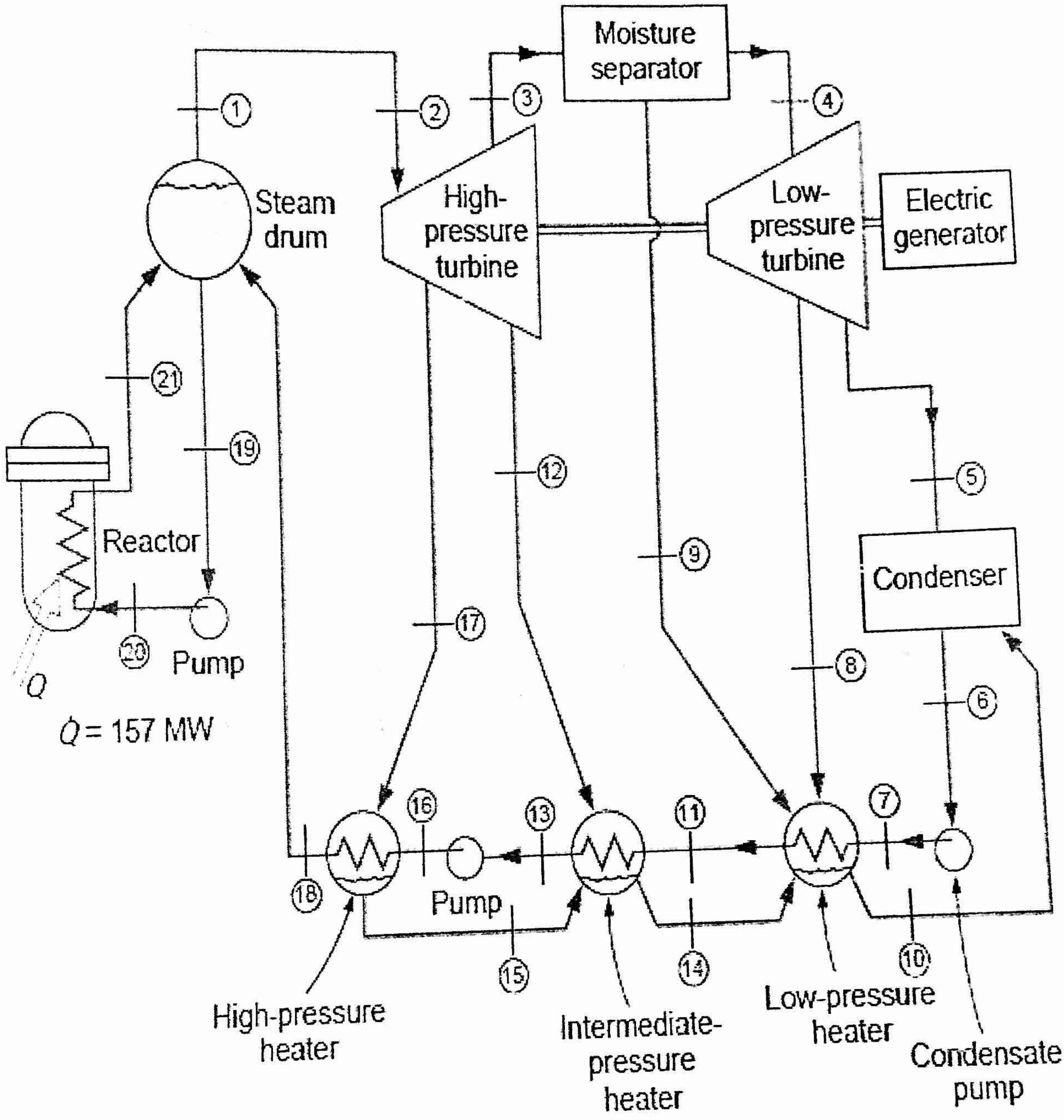


FIGURE P6.106